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(54) Title: MULTIPLE DATA LAYER OPTICAL DISK DRIVE SYSTEM WITH FIXED ABERRATION CORRECTION AND OPTIMUM INTERLAYER SPACING

(57) Abstract

A multiple data layer optical disk drive system has fixed aberration correction and uses a disk with maximum interlayer spacing for reduced interlayer crosstalk. In one embodiment the multiple data layer disk has a substrate with a thickness that is reduced by approximately one-half the thickness of the spacer layer that separates the first and last data layers. The disk is designed to operate with a lens that has spherical aberration correction to compensate for the thickness of a conventional single data layer disk. This allows the disk drive to handle multiple data layer disks as well as to be backward compatible and thus handle conventional single data layer disks. The thickness of the substrate material plus one-half the thickness of the spacer layer material (which may have a different index of refraction than the substrate material) is equivalent, for purposes of spherical aberration correction, to the thickness of the substrate material used in the conventional single data layer disk. The focused spot with minimum spherical aberration is thus located at the middle of the spacer layer rather than one the first data layer. The spacer layer thickness is selected so that when the focused spot is located on either the first or last data layer there is some deliberately designed spherical aberration, although an amount that is acceptable. As a result the thickness of the spacer layer can be significantly increased to thereby reduce interlayer crosstalk. In another embodiment the substrate thickness and spacer layer thickness are selected and then the lens is corrected for spherical aberration corresponding to the thickness of substrate material plus one-half the thickness of spacer layer material.

MULTIPLE DATA LAYER OPTICAL DISK DRIVE SYSTEM WITH FIXED ABERRATION CORRECTION AND OPTIMUM INTERLAYER SPACING

5   The present invention relates to optical disks that have multiple data layers and optical disk drives that are operable with such disks.

Optical data storage systems provide a means for storing great quantities of data. The data is accessed by focusing a laser beam to a small spot on the data layer of the optical medium and then detecting the
10   reflected light beam. Optical disk drive systems with removable optical disks are the most common form of optical storage. Various kinds of such systems are known. In a ROM (Read Only Memory) system, such as a compact disk system (e.g. CD-ROM, CD-Audio, CD-Video), data is permanently embedded as marks in the disk at the time of manufacture of the disk. The
15   data is detected as a change in reflectivity as the laser beam passes over the data marks. A WORM (Write-Once Read-Many) system allows the user to write data by making marks, such as pits, in a recording layer of the optical disk. Once the data is recorded onto the disk it cannot be erased. The data in a WORM system is also detected as a change in
20   reflectivity. There are also erasable optical data storage systems, such as phase change and magneto-optic (M-O) systems. While phase change systems also read data by sensing a change in reflectivity, M-O systems read data by measuring the rotation of the incident polarization caused by the M-O media.
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To increase the storage capacity of an optical disk, multiple data layer systems have been proposed. An optical disk having two or more data layers may be accessed at different layers by changing the focal position of the lens. IBM's US Patent 5,202,875 describes a multiple data layer
30   optical disk drive system wherein the optical disk comprises either a plurality of substrates, each with a data layer spaced apart by air gaps, or a plurality of data layers in a solid structure. US Patent 4,450,553 assigned to U.S. Philips, uses a solid structure with multiple data layers, where each data layer is a CD type data layer. In such multiple
35   data layer optical disk drive systems, the light from the laser must pass through one or more of the light-transmissive disk substrates to access the data layers on the different substrates. The focusing of the light through a relatively thick light-transmissive substrate introduces spherical aberration into the light beam. If not corrected, this prevents
40   the nearly diffraction-limited spot size from being achieved. In the case of conventional single-disk optical disk drives, this can be corrected by slightly changing the shape of the surfaces of the focusing lens by a fixed amount because the amount of substrate material through which the light must pass remains fixed. However, in multiple data layer optical
45   disk drives, because the light is required to be focused through different

numbers and thicknesses of substrates depending on which data layer is being accessed, some form of adjustable active compensation for spherical aberration is required. For example, US Patent 5,097,464 assigned to Matsushita, describes a multiple data layer CD system that uses a lens with aberration corrected for the data layer farthest from the lens and an optical path length corrector that is inserted into the optical path when the laser spot is focused on data layers closer to the lens. Also, IBM's US Patent 5,202,875 describes a multiple data layer optical disk drive system with an active aberration compensator.

An additional problem in multiple data layer systems is the need to be compatible with conventional single data layer disks, such as CDs. For example, conventional Cds use a 1.20 mm thick polycarbonate substrate. A multiple data layer CD disk drive must be able to focus a nearly diffraction-limited spot on the data layer of the conventional single data layer disk as well as on the multiple data layers of the newer multiple data layer disk.

Still another problem that occurs in multiple data layer systems is crosstalk caused by undesirable data, focus error and tracking error signals from adjacent data layers interfering with the signals from the desired data layer. These undesired signals are known as interlayer crosstalk. To avoid this problem it is necessary to maintain a relatively large spacing between the data layers. However, a relatively large spacing between data layers that are separated by solid spacer material increases the overall thickness of the disk and the amount of required active spherical aberration correction, both of which are undesirable.

What is needed is an optical disk drive that operates with single and multiple data layer disks and that minimizes the effects of spherical aberration and interlayer crosstalk.

In accordance with the present invention, there is now provided an optical data storage system comprising: a laser light source; an optical data medium comprising a partially light-transmissive first data layer, a light-reflective second data layer, and a light-transmissive spacer layer located between and separating the first and second data layers by the thickness of said spacer layer; a lens located between the laser light source and the first data layer of the medium for focusing the laser light to a spot, the lens having correction for spherical aberration so that the focused spot has approximately minimum spherical aberration when located between the first and second data layers.

Viewing the present invention from a second aspect, there is now provided an optical data disk of the type readable by laser light

transmitted through a lens having correction for spherical aberration, the disk comprising: a light-transmissive substrate having a thickness t1 and a first surface that forms a disk outer face onto which the laser light is incident from the lens; a partially light-transmissive first data layer on the substrate surface opposite said first surface; a light-reflective second data layer; and a light-transmissive spacer layer having a thickness t2 and located between and separating the first and second data layers, the thickness t1 of substrate material plus one-half the thickness t2 of spacer layer material being substantially equivalent to the thickness of material corresponding to said correction for spherical aberration of the lens.

Viewing the present invention from a third aspect, there is now provided an optical disk drive system comprising: a laser light source; an optical disk comprising (a) a light-transmissive substrate having a first surface that forms a disk outer face onto which the laser light is incident, (b) a partially light-transmissive first data layer on the substrate surface opposite said first surface, (c) a light-reflective second data layer, and (d) a light-transmissive spacer layer located between and separating the first and second data layers by the thickness of said spacer layer; a motor attached to the disk for rotating the disk; a lens located between the laser light source and said first surface of the substrate for focusing the laser light to a spot, the lens having correction for spherical aberration caused by the total substrate thickness plus approximately one-half the spacer layer thickness; and means connected to the lens for moving the lens relative to the disk so the focused spot can be moved from one data layer to another data layer; whereby when the spot is located on the first data layer it possesses spherical aberration because the total substrate and spacer layer material thickness traversed is less than the spherical aberration correction thickness by approximately one-half the spacer layer thickness, and when the spot is located on the second data layer it possesses spherical aberration because the total substrate and spacer layer material thickness traversed is greater than the spherical aberration correction thickness by approximately one-half the spacer layer thickness.

Viewing the present invention from a fourth aspect, there is now provided a compact disk (CD) optical disk drive system comprising: a laser light source; a CD optical disk comprising (a) a light-transmissive substrate having a thickness t1 and a first surface that forms a disk outer face onto which the laser light is incident, (b) a partially light-transmissive first data layer on the substrate surface opposite said first surface, (c) a light-transmissive spacer layer having a thickness t2 and located on the first data layer, and (d) a light-reflective second data layer on the spacer layer and separated from the first data layer by

approximately t2; a motor attached to the disk for rotating the disk; a
lens located between the laser light source and said first surface of the
substrate for focusing the laser light to a spot, the lens having a fixed
correction for spherical aberration; and means connected to the lens for
moving the lens relative to the disk so the focused spot can be moved from
one data layer to another data layer, the fixed spherical aberration
correction of the lens having a value such that a nearly diffraction
limited focused spot occurs approximately at a distance t1 plus t2/2 from
said first surface of the disk.

Viewing the present invention from a fifth aspect, there is now
provided an optical data storage disk of the type readable by laser light
transmitted through a lens having a correction for spherical aberration
corresponding to a fixed thickness of light-transmissive material having a
known index of refraction, the disk comprising a light-transmissive
substrate, a partially light-transmissive first data layer, a light-
reflective second data layer, and a light-transmissive spacer layer
located between and separating the first and second data layers, the
thickness of the light-transmissive substrate plus one-half the
thickness of the spacer layer being substantially equivalent to said fixed
thickness of light-transmissive material having said known index of
refraction for which the lens is spherical aberration corrected.

In a preferred embodiment of the present invention there is provided
a multiple data layer optical disk drive system that has fixed aberration
correction and uses a disk with maximum interlayer spacing for reduced
interlayer crosstalk. In one embodiment the multiple data layer disk has
a substrate with a thickness that is reduced by approximately one-half the
thickness of the spacer layer that separates the first and last data
layers. The disk is designed to operate with a lens that has spherical
aberration correction to compensate for the thickness of a conventional
single data layer disk. This allows the disk drive to handle multiple
data layer disks as well as to be backward compatible and thus handle
conventional single data layer disks. The thickness of the substrate
material plus one-half the thickness of the spacer layer material (which
may have a different index of refraction than the substrate material) is
equivalent, for purposes of spherical aberration correction, to the
thickness of the substrate material used in the conventional single data
layer disk. The focused spot with minimum spherical aberration is thus
located at the middle of the spacer layer rather than on the first data
layer. The spacer layer thickness is selected so that when the focused
spot is located on either the first or last data layer there is some
deliberately designed spherical aberration, although an amount that is
acceptable. As a result the thickness of the spacer layer can be
significantly increased to thereby reduce interlayer crosstalk. In

another embodiment the substrate thickness and spacer layer thickness are
selected and then the lens is corrected for spherical aberration
corresponding to the thickness of substrate material plus one-half the
thickness of spacer layer material.

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Preferred embodiments of the present invention will now be described
with reference to the accompanying drawings, in which:

Fig. 1 is a schematic diagram of an optical disk drive system
10   embodying the present invention in the form of a CD system;

Fig. 2 is a schematic diagram of the optical head and two-layer disk
of the optical disk drive system;

15   Fig. 3 is a block diagram of a controller system of the optical disk
drive system;

Fig. 4 is a graph illustrating the light intensity of a focused spot
as a function of position across the beam for two cases: Curve A with
20   minimal spherical aberration and Curve B with significant spherical
aberration;

Fig. 5 is a graph of Strehl ratio, for two materials with different
indices of refraction, as a function of distance from the location at
25   which the spherical aberration is a minimum for a lens with N.A.=0.45;

Fig. 6 is a sectional view of the two layer disk illustrating the
spot with minimum spherical aberration located in the middle of the spacer
layer;

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Fig. 7 is a comparison of 1-Strehl ratio as a function of achievable
data layer separation (spacer layer thickness) for two optical disk drive
systems with a lens with N.A.=0.55, one where the spot with minimum
spherical aberration is located on the first data layer, and one where the
35   spot with minimum spherical aberration is located in the middle of the
spacer layer; and

Fig. 8 is a sectional view of an air-incident two layer disk with a
thin dust cover illustrating the spot with minimum spherical aberration
40   located in the middle of the spacer layer.

Fig. 1 is a schematic diagram of an optical disk data storage system
according to the present invention designated by the general reference
number 10. System 10 will be explained in terms of a CD optical disk
45   drive system. System 10 includes an optical data storage disk 12 which is

preferably removably mounted on a clamping spindle 14 as is known in the art. Spindle 14 is attached to a spindle motor 16, which in turn is attached to a system chassis 20. Motor 16 rotates spindle 14 and disk 12.

5   An optical head 22 is positioned below disk 12. Head 22 is attached to an arm 24, which in turn is connected to an actuator device such as a voice coil motor 26. Voice coil motor 26 is attached to chassis 20 and moves arm 24 and head 22 in a radial direction below disk 12.

10   Fig. 2 shows a schematic diagram of one embodiment of the optical head 22 and disk 12 of Fig. 1. Optical head 22 includes a laser diode 200, which may be a gallium-aluminum-arsenide diode laser producing a primary beam of light 202 at approximately 780 nanometers wavelength. Beam 202 is first diffracted by grating 201 to produce two secondary beams

15   for tracking, in addition to the primary data beam, and then collimated by lens 203. The resulting three-component beam 204 then passes to a beamsplitter 205. A portion of beam 204 is reflected by beamsplitter 205 to a lens 206 and an optical detector 207. Detector 207 is used to monitor the power of laser beam 204. Beam 204 from beamsplitter 205 next

20   passes to and is reflected by a mirror 208. Beam 204 then passes through a focus lens 210 and is focused to a diffraction-limited spot. Lens 210 is mounted in a holder 214, the position of which is adjusted relative to disk 12 by a focus actuator motor 216, which may be a voice coil motor. Movement of the lens 210 by the focus actuator moves the focused spot

25   between the two data layers 52, 62 of disk 12.

       A portion of the light beam 204 is reflected from a data layer 52, 62 as a reflected beam 220. Beam 220 returns through lens 210 and is reflected by mirror 208. At beamsplitter 205, beam 220 is directed

30   through an astigmatic lens 232 and onto a multielement optical detector 234.

       Fig. 3 is a block diagram of a controller system of the optical disk drive system and is designated by the general reference number 300. The

35   multielement detector 234 (Fig. 2) generates output signals that provide a data signal, a focus error signal (FES), and a tracking error signal (TES). These signals are amplified by signal amplifier 236 and sent directly to controller 314. A peak detector 310 also receives the FES, and a peak detector 312 also receives the TES from amplifier 236.

40   Controller 314 also receives input signals from FES peak detector 310, TES peak detector 312, and laser power detector 207. Controller 314 is a microprocessor-based disk drive controller. Controller 314 is also connected to and controls the laser 200, head motor 26, spindle motor 16, and focus actuator motor 216.

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Referring again to Fig. 2, the disk 12 is shown in cross-section.
The disk 12 comprises a light-transmissive substrate 40, typically
polycarbonate. A first surface 41 of substrate 40 faces lens 210 and is
the side onto which the light is incident. The opposite surface of
5   substrate 40 has formed on it a first data layer 52. Data layer 52 is a
pattern of pits or depressions formed into the surface of substrate 40 and
covered with a film of partially light-transmissive material. Data
layer 52 is formed by conventional injection molding, embossing, or
photopolymer replication. Substrate 40 and first data layer 52 are
10   similar to that in conventional CDs, with the exception that the film
covering the pattern of pits on the substrate surface is partially
light-transmissive rather than totally reflective. This film of material
can be formed of any conventional semiconductor material (e.g., amorphous
Si, SiC, GaSb), dielectric material (e.g., ZrO_2, SiN), or metallic
15   material (e.g., Al, Au). These materials can be deposited by sputtering
or evaporation, as is known in the art, and have a thickness in the range
of 30-3000 Angstroms. A light-transmissive spacer layer 44 is formed over
data layer 52. The spacer layer can be formed of a photopolymer material
deposited by spin-coating. Alternatively the spacer layer 44 can be
20   formed by a lamination process, i.e., gluing a thin plastic sheet,
embossed with data layer 62, onto the covering film of the data layer 52
on substrate 40. The surface of spacer layer 44 opposite the surface in
contact with data layer 52 has formed on it a second data layer 62. Data
layer 62 also comprises a pattern of pits, formed on the surface of the
25   spacer layer 44, and a covering film of light-reflective material, such as
an aluminum alloy. The aluminum alloy covering film is preferably totally
reflective if the data layer 62 is the last data layer in the multiple
data layer disk, and has a typical thickness in the range of 100-1000
Angstroms. The embossed pattern of data layer 62 can be formed by a
30   photopolymerization process with a stamper in contact with the polymer,
with the polymer cured by ultraviolet radiation. If the spacer layer is
formed by lamination, the data layer 62 can be pre-embossed onto the
plastic sheet before the sheet is glued to substrate 40. Typically the
depth of the pits in the embossed patterns in data layers 52, 62 is in the
35   range of 1000 to 2000 Angstroms. Finally, a protective layer 70 of a
photopolymer is formed over data layer 62 by spin-coating followed by
curing. The two-layer CD as shown in Fig. 2 is a dual data layer disk.
The substrate 40 has a thickness t1 and is formed of light-transmissive
material with an index of refraction n1. Spacer layer 44 has a
40   thickness t2 and is formed of light-transmissive material with an index of
refraction n2. Additional data layers may be used in the disk 12. For
example, additional embossed patterns and partially light-transmissive
films can be formed between the first and second data layers 52, 62.

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The operation of optical storage system 10 (Fig. 1) may now be understood with reference to Figs. 2 and 3. Controller 314 controls motor 16 that rotates disk 12 and motor 26 that moves optical head 22 to the proper position below disk 12. Laser 200 is energized to read data from disk 12. The beam 204 is focused by lens 210 to a nearly diffraction-limited spot and this focused spot is located on the desired one of the data layers 52, 62. The reflected beam 220 returns and is directed to the multielement detector 234 by the astigmatic lens 232. The FES, TES, and data signals are output by detector 234 and amplified by amplifier 236 (Fig. 3). The FES is used by controller 314 in a conventional servo control technique to control focus actuator motor 216 so that lens 210 maintains the spot on the desired data layer (e.g., data layer 52) as the disk 12 rotates. When it is desired to read data from data layer 62, the controller 314 signals focus actuator motor 216 to move the lens so the spot is moved from data layer 52 to data layer 62. When the spot is located on data layer 62, the light from lens 210 traverses the entire thickness t1 of substrate 40 and thickness t2 of spacer layer 44.

In optical disk drive systems it is desired to make the diameter of the focused spot as small as possible and to have minimum spherical aberration. Because the light is focused through the substrate, the refractive index and thickness of the substrate must be included in the design of the objective lens. Thus the lens is designed to have spherical aberration correction that corresponds to a fixed thickness of light-transmissive material having a known index of refraction. Fig. 4 is a graph of the light intensity of the focused spot as a function of lateral position from the center of the spot for two different spots: one having minimum spherical aberration and one having significant spherical aberration due to a non-optimum substrate thickness. Curve A in Fig. 4 represents a spot with minimum spherical aberration, and is an essentially Gaussian distribution of light intensity. The diffraction-limited spot diameter is defined as the full width at half the maximum intensity amplitude, and is depicted for Curve A in Fig. 4. Curve B in Fig. 4 represents a spot with spherical aberration and illustrates a lower peak intensity and the presence of side lobes. In an optical disk drive, if the lens is not corrected for the proper substrate thickness, the spot on the data layer will possess spherical aberration. This is undesirable because the data, focus error and tracking error signals all rely upon having maximum optical resolution.

The ratio of the peak intensity of a spot with aberration to the peak intensity of the nearly diffraction-limited spot without aberration is referred to as the Strehl ratio. Fig. 5 is a graph of Strehl ratio as a function of thickness deviation from the substrate thickness to which the lens was designed, for two materials having different indices of

refraction, for a lens with N.A.=0.45. The solid line is the Strehl ratio
for material with an index of refraction of 1.57 (e.g., polycarbonate) and
the dashed line is the Strehl ratio for material with an index of
refraction of 1.10. At a thickness deviation of zero the light has
5   traversed the precise distance for which the lens has been corrected for
spherical aberration, so the Strehl ratio is theoretically 1.0. However,
if the light traverses more or less material the spot will possess
spherical aberration. In the case of a conventional CD system with n=1.57
and a lens having a numerical aperture (N.A.) of 0.45, the minimum
10   acceptable Strehl ratio is approximately 0.9. This corresponds to a
deviation of the material thickness of approximately +/- 0.125 mm. For a
two data layer system like that shown and described in Fig. 2, this means
that if the spacer layer 44 is also of material with an index of
refraction near 1.57, then the spacer layer can not be any thicker than
15   approximately 0.125 mm or the spot will have unacceptably high spherical
aberration when it is focused on data layer 62. For a lens with N.A.=0.55
with the same Strehl ratio requirement of 0.9 the thickness of the spacer
layer can not be larger than approximately 0.05 mm. Thus the problem of
spherical aberration in a multilayer optical disk drive system is best
20   solved by making the spacer layer as thin as possible. However, a
separate problem in a multilayer optical disk drive system is interlayer
crosstalk from adjacent data layers when the spot is located on the
desired data layer. This problem is best solved by making the spacer
layer as thick as possible.
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In the present invention the multiple data layer optical disk drive
system is designed so that the focused spot with minimum spherical
aberration is not located on any data layer. Instead the spot is located
preferably at the midpoint between the two data layers nearest and
30   farthest from the lens. In the case of a two layer CD optical disk drive
system like that shown in Fig. 2, the disk drive is designed so that the
spot with minimum spherical aberration is located at the middle of spacer
layer 44.

35   Thus, as shown in Fig. 6, the focused spot with minimum spherical
aberration is illustrated as being located at approximately the middle of
spacer layer 44 (i.e., t2/2 distance from both data layers 52 and 62).
The amount of material traversed by the light to this point is
approximately the t1 thickness of substrate 40, with index of refraction
40   of n1, and one-half the thickness of spacer layer 44 (t2/2), with index of
refraction of n2. In the preferred embodiment, the lens 210 is like that
used in conventional single layer disk drive systems, i.e., corrected
for 1.20 mm polycarbonate (n1=1.57) substrate thickness. However, in the
preferred embodiment the substrate 40 has a thickness not equal to the
45   conventional substrate thickness, but to the conventional thickness less

t2/2 of the spacer layer 44 thickness. In the CD drive embodiment of the
present invention, with a lens having N.A.=0.45, the substrate 40
thickness t1 is approximately 1.075 mm and spacer layer 44 thickness t2 is
approximately 0.250 mm. For a lens with N.A.=0.55 the substrate 40
thickness t1 would be approximately 1.15 mm and spacer layer 44
thickness t2 would be approximately 0.10 mm. The spacer layer 44 material
is preferably a polymer which has an index of refraction sufficiently
similar to that of polycarbonate that it is only a second order effect in
the spherical aberration correction and need not be factored into the
selection of substrate thickness t1. However, if the index of refraction
of the spacer layer is different from that of the substrate, the
thickness t1 of the substrate is adjusted so that t1 of substrate material
with index of refraction n1 and t2/2 of spacer layer material with index
of refraction n2 together are equivalent to the thickness of material to
which the lens is spherical aberration corrected.

The thickness t2 of spacer layer 44 is selected based on the minimum
acceptable Strehl ratio, which in turn depends on the N.A. of the lens and
the index of refraction of the substrate material. The thickness t2 is
selected so that t2/2 corresponds to the maximum thickness variation where
the spherical aberration is still acceptable. For a CD two data layer
drive with N.A.=0.45 this is t2/2=0.125 mm (Strehl ratio=0.9) or
t2=0.250 mm. The result is a doubling of the spacer layer thickness over
what would be the case if the focused spot with minimum spherical
aberration were located on the first data layer. The effect of interlayer
crosstalk is substantially reduced while the amount of spherical
aberration on both data layers is still acceptable.

An advantage of this embodiment of the present invention is that
since the lens remains spherical aberration corrected for the conventional
substrate thickness of a single data layer optical disk, the optical disk
drive can also operate with conventional single data layer disks. Thus in
the case of a CD optical disk drive system, the drive is operable with a
two data layer disk (substrate thickness t1=1.075 mm and spacer layer
thickness t2=0.250 mm) and is backward compatible with existing single
layer CDs (substrate thickness 1.20 mm).

In an alternative embodiment of the present invention the substrate
and spacer layer thicknesses are selected to optimize performance of the
multiple data layer disk and the lens is spherical aberration corrected
for the selected t1 of substrate with index of refraction n1 and t2 of
spacer layer with index of refraction n2. In the case of CDs the
conventional 1.20 mm substrates can be used for the two data layer system
and the spacer layer can be made 0.250 mm thick. The lens would then be
corrected for 1.325 mm [1.20 + (t2/2=0.125)] of material

(assuming N.A.=0.45 and the spacer layer is made of material with an index
of refraction close enough to 1.57 that it has negligible effect on
spherical aberration correction).

5   The method of correcting lenses for known spherical aberration in
systems having a plano-parallel substrate is a well-known technique. The
wavelength of the light and the thicknesses and indices of refraction of
the material through which the light must traverse are used to generate a
polynomial equation that represents the shape of the lens. This method is
10   described, for example, by R. Kingslake, Lens Design Fundamentals,
pp. 119-122 and 205-208, Academic Press, 1978, and is not part of the
present invention.

       Fig. 7 illustrates the increased data layer spacing that is
15   achievable with the present invention for a lens with N.A.=0.55. For
example, with N.A.=0.55 and an acceptable Strehl ratio of 0.9 (1-Strehl
ratio of 0.1 on Fig. 7), a disk drive system with a spot with minimum
spherical aberration located on the first data layer indicates that the
spacer layer can be no thicker than approximately 0.065 mm. However, with
20   the present invention, where the disk drive system is designed so that
spot with minimum spherical aberration is located in the middle of the
spacer layer, the spacer layer thickness can be doubled to 0.13 mm. In
the preferred embodiment a Strehl ratio of 0.9 has been used. However,
higher or lower values of Strehl ratio may be desired, depending on the
25   particular parameters of the disk drive system, such as the N.A. of the
lens and the indices of refraction of the substrate and spacer layer.
The multiple data layer disk shown in Fig. 6 is illustrated as a solid
structure where the outer layers are the substrate 40 and protective
layer 70. In the case of a CD system the substrate 70 is polycarbonate
30   with a thickness of either 1.20 mm or 1.20 mm less t2/2, depending on the
embodiment. However, the multiple data layer disk may also be fabricated
by bonding two thinner single data layer disks together. In this type of
structure the protective layer 70 is a second substrate identical to
substrate 40. For example, in the case of a CD system, two substrates
35   of 0.60 mm thickness and each having a data layer are bonded together with
a light-transmissive material, such as a conventional photopolymer, that
serves as the spacer layer. The data layer on the substrate closest to
lens 210 has a partially light-transmissive covering film over its pit
pattern and the data layer on the substrate farthest from lens 210 has a
40   totally light-reflective covering film on its pit pattern.

       Fig. 8 illustrates the invention with an alternative type of
multiple data layer disk 90. The disk 90 includes an aluminum disk
blank 91, a data layer 92 farthest from lens 210 formed on disk blank 91,
45   a spacer layer 93 on data layer 92 and a data layer 94 nearest to lens 210

formed on spacer layer 93. A plastic ring 95 is bonded to aluminum disk
blank 91 and extends around the outer perimeter of disk blank 91. The
ring 95 supports a transparent plastic dust cover 96. The dust cover 96
is typically 100 microns thick and is stretched across and bonded to
ring 95. The dust cover 96 forms an air gap of 0.2-2.0 mm between it and
the data layer 94. Both data layers 92, 94 are recordable phase change
WORM data layers, typically formed of In-Sb-Sn. The first data layer 94
closest to lens 210 is 60-120 Angstroms thick and is thus by its thickness
partially light-transmissive. The second data layer 92 farthest from
lens 210 is 400-2000 Angstroms thick and thus has an increased
reflectivity over data layer 94. The spacer layer 93 is a spin-coated and
cured photopolymer film with a typical thickness of 0.05-0.15 mm. As
shown in Fig. 8 the focused spot with minimum spherical aberration is
located at the middle of spacer layer 93. In this embodiment of the
invention the "substrate" through which the light passes to the data
layers 92, 94 is the dust cover 96. Thus the spherical aberration
correction for the lens 210 is the correction needed due to passage of the
light through the thickness of dust cover 96 (with its index of
refraction n1) and through one-half the thickness of spacer layer 93 (with
its index of refraction n2). Passage of light through air does not
introduce any spherical aberration so the air gap between dust cover 96
and first data layer 94 does not figure into the spherical aberration
correction for the lens 210.

The invention has been described with a two-layer disk. However,
the invention is also applicable where there are additional data layers
located between the first data layer (the one nearest the lens) and the
second or last data layer (the one farthest from the lens). For example,
in an eight data layer disk, where the spacer layer is defined as the
thickness between the nearest and farthest data layers, the drive would be
designed so that the lens is still spherical aberration corrected for t1
plus t2/2 (where t2 is the thickness of the solid light-transmissive
material between the nearest and farthest data layers), and the nearly
diffraction-limited spot would be located between the fourth and fifth
data layers from the lens.

The invention has also been described relative to a CD system.
However the invention is fully applicable with any multiple data layer
optical disk, such as magneto-optic, phase change, or ablative
write-once/read-many (WORM) disks.

While the preferred embodiments of the present invention have been
illustrated in detail, it should be apparent that modifications and
improvements may be made to the invention without departing from the scope
of the invention as described in the following claims.

CLAIMS

1.   An optical data storage system comprising:

5   a laser light source;

    an optical data medium comprising a partially light-transmissive
first data layer, a light-reflective second data layer, and a light-
transmissive spacer layer located between and separating the first and
10   second data layers by the thickness of said spacer layer;

    a lens located between the laser light source and the first data
layer of the medium for focusing the laser light to a spot, the lens
having correction for spherical aberration so that the focused spot has
15   approximately minimum spherical aberration when located between the first
and second data layers.

2.   A system as claimed in claim 1, wherein the optical data medium
comprises a light-transmissive substrate having a first surface, opposite
20   the first data layer, onto which the laser light is incident.

3.   A system as claimed in claim 2, wherein the optical data medium is
in the form of an optical disk.

25   4.   A system as claimed in claim 3 comprising:

    a motor attached to the disk for rotating the disk; and

    means connected to the lens for moving the lens relative to the disk
30   so the focused spot can be moved from one data layer to another data
layer, the lens having correction for spherical aberration caused by the
total substrate thickness plus approximately one-half the spacer layer
thickness; whereby when the spot is located on the first data layer it
possesses spherical aberration because the total substrate and spacer
35   layer material thickness traversed is less than the spherical aberration
correction thickness by approximately one-half the spacer layer thickness,
and when the spot is located on the second data layer it possesses
spherical aberration because the total substrate and spacer layer material
thickness traversed is greater than the spherical aberration correction
40   thickness by approximately one-half the spacer layer thickness.

5.   A system as claimed in claim 4 wherein the lens has correction for
spherical aberration caused by a substrate having a thickness t1 and an
index of refraction n1, and wherein the disk substrate is formed of

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material having an index of refraction n1 and a thickness of approximately t1-t2/2, where t2 is the spacer layer thickness.

6.   A system as claimed in claim 4 wherein the disk substrate is formed of material having an index of refraction n1 and a thickness of approximately t1 and the spacer layer is formed of material having an index of refraction n2 and a thickness of approximately t2, and wherein the lens has correction for spherical aberration caused by t1 thickness of substrate material and t2/2 thickness of spacer layer material.

7.   A system as claimed in claim 4 wherein the lens has correction for spherical aberration caused by approximately 1.20 mm of polycarbonate, and wherein the disk substrate is formed of polycarbonate and has a thickness of approximately 1.20 mm less one-half the spacer layer thickness.

8.   A system as claimed in claim 4 wherein the lens has correction for spherical aberration caused by approximately 0.60 mm of polycarbonate, and wherein the disk substrate is formed of polycarbonate and has a thickness of approximately 0.60 mm less one-half the spacer layer thickness.

9.   A system as claimed in claim 4 wherein the disk substrate is formed of polycarbonate and has a thickness of approximately 1.20 mm and wherein the lens has correction for spherical aberration caused by 1.20 mm of polycarbonate plus approximately one-half the spacer layer thickness.

10.   A system as claimed in claim 4 wherein the disk substrate is formed of polycarbonate and has a thickness of approximately 0.60 mm and wherein the lens has correction for spherical aberration caused by 0.60 mm of polycarbonate plus approximately one-half the spacer layer thickness.

11.   An optical data disk of the type readable by laser light transmitted through a lens having correction for spherical aberration, the disk comprising:

a light-transmissive substrate having a thickness t1 and a first surface that forms a disk outer face onto which the laser light is incident from the lens;

a partially light-transmissive first data layer on the substrate surface opposite said first surface;

a light-reflective second data layer; and

a light-transmissive spacer layer having a thickness t2 and located between and separating the first and second data layers, the thickness t1

of substrate material plus one-half the thickness t2 of spacer layer
material being substantially equivalent to the thickness of material
corresponding to said correction for spherical aberration of the lens.

5   12.   A disk as claimed in claim 11 wherein the disk is a compact disk
(CD), wherein the substrate is formed of polycarbonate, and wherein the
amount of spherical aberration required to be corrected by the
thickness t1 of substrate material plus one-half the thickness t2 of
spacer layer material is substantially equivalent to the amount of
10   spherical aberration required to be corrected by approximately
1.20 millimeters of polycarbonate.

      13.   A disk as claimed in claim 12 wherein the disk is a compact disk
(CD), wherein the substrate is formed of polycarbonate, and wherein the
15   amount of spherical aberration required to be corrected by the
thickness t1 of substrate material plus one-half the thickness t2 of
spacer layer material is substantially equivalent to the amount of
spherical aberration required to be corrected by approximately
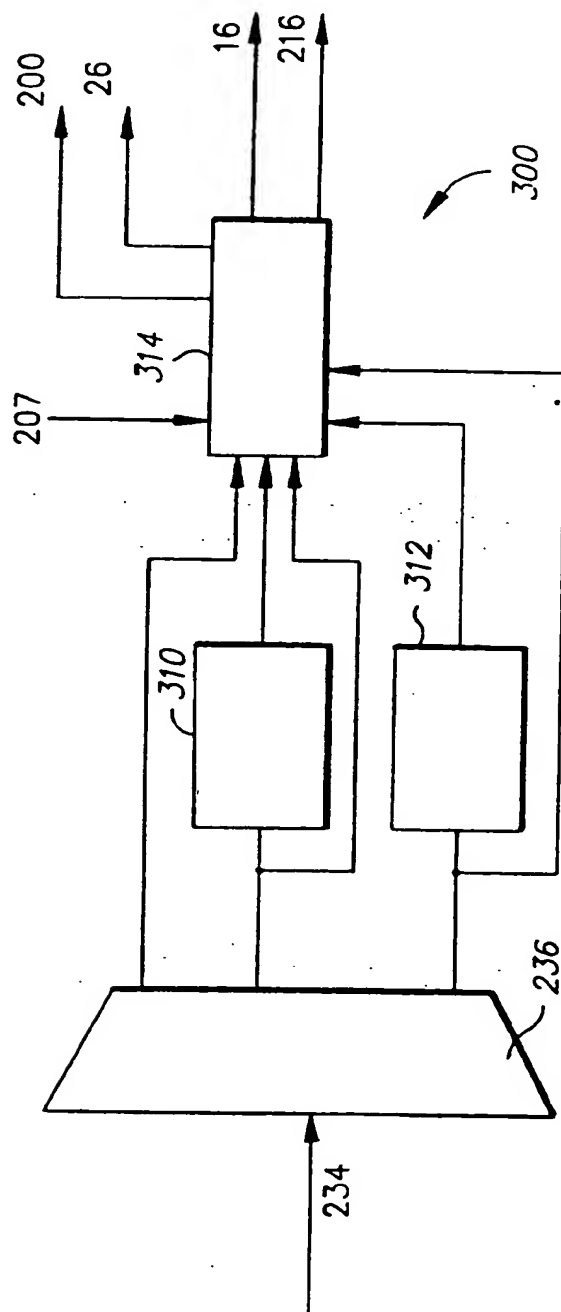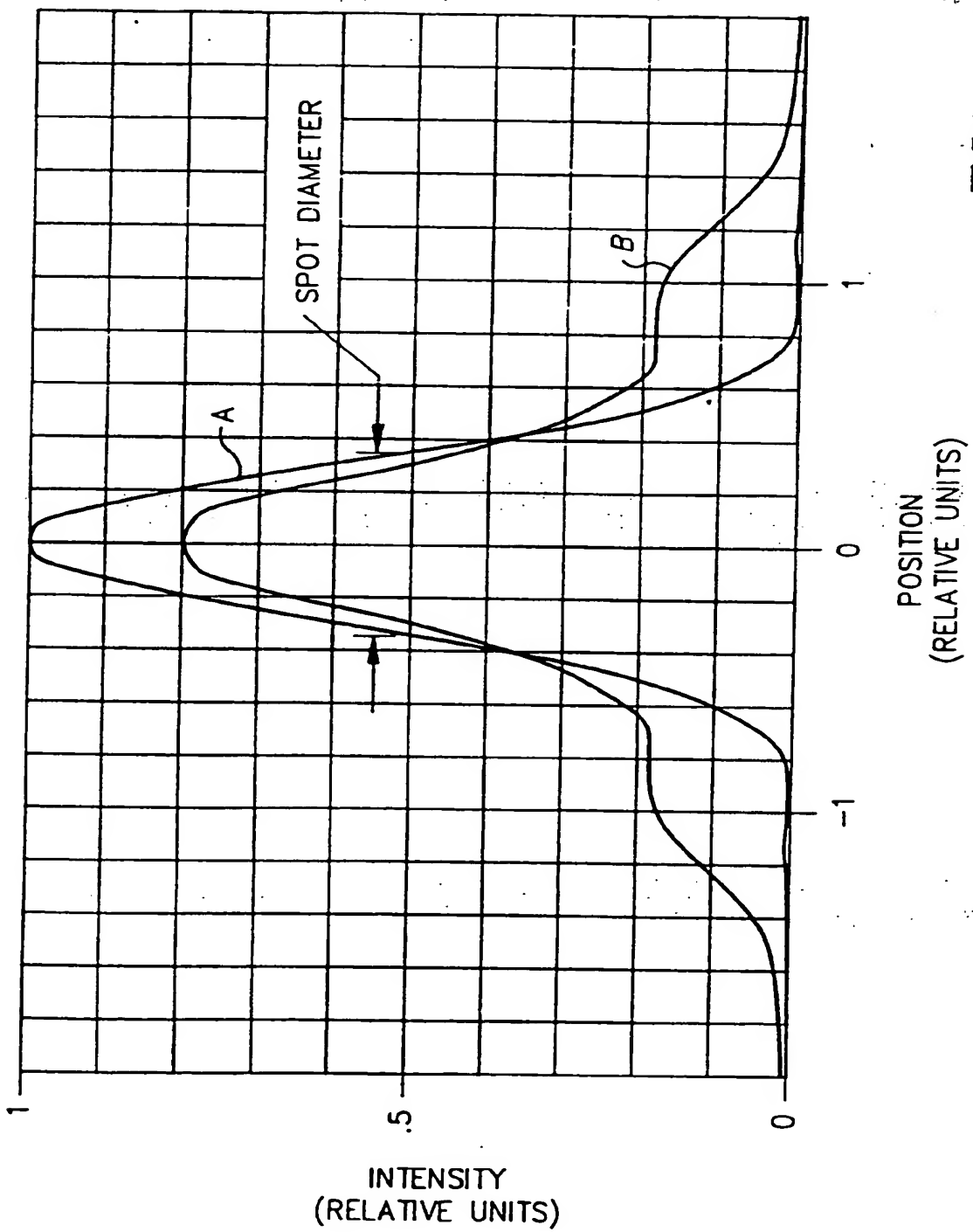0.60 millimeters of polycarbonate.

20
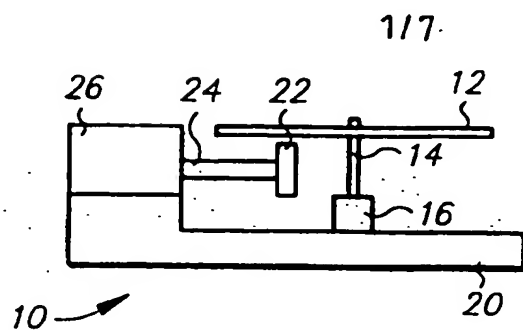
FIG 1
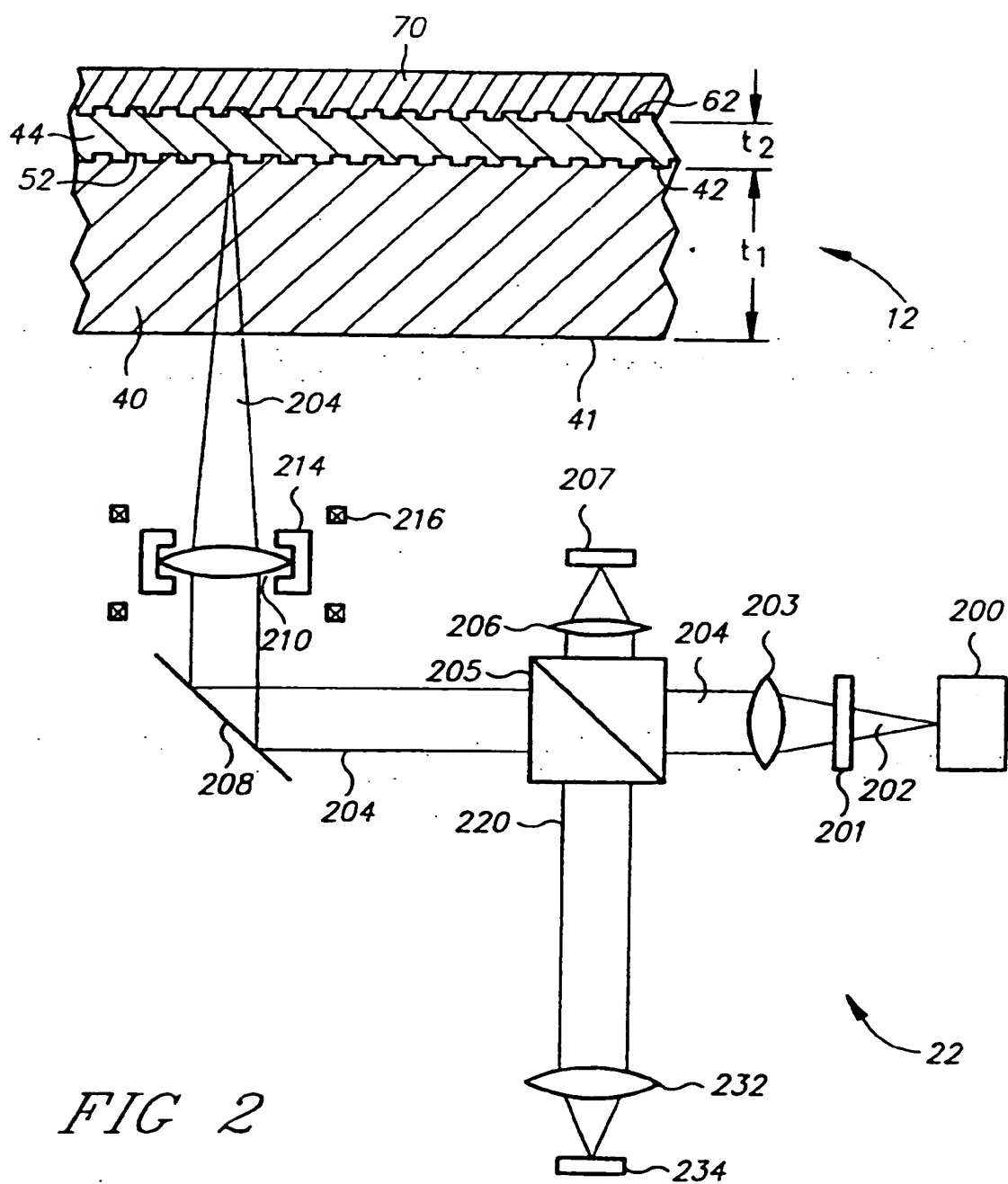
FIG 2
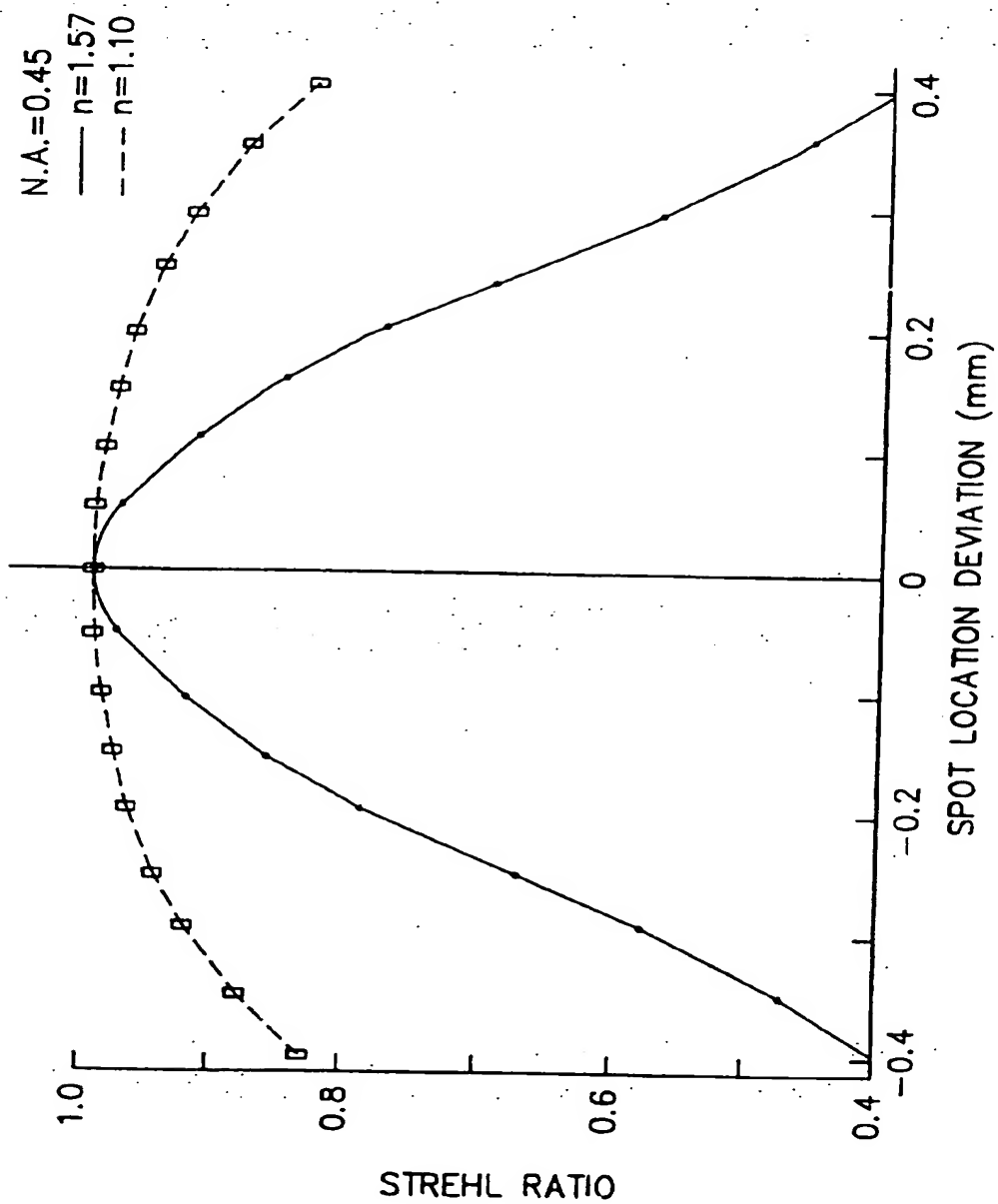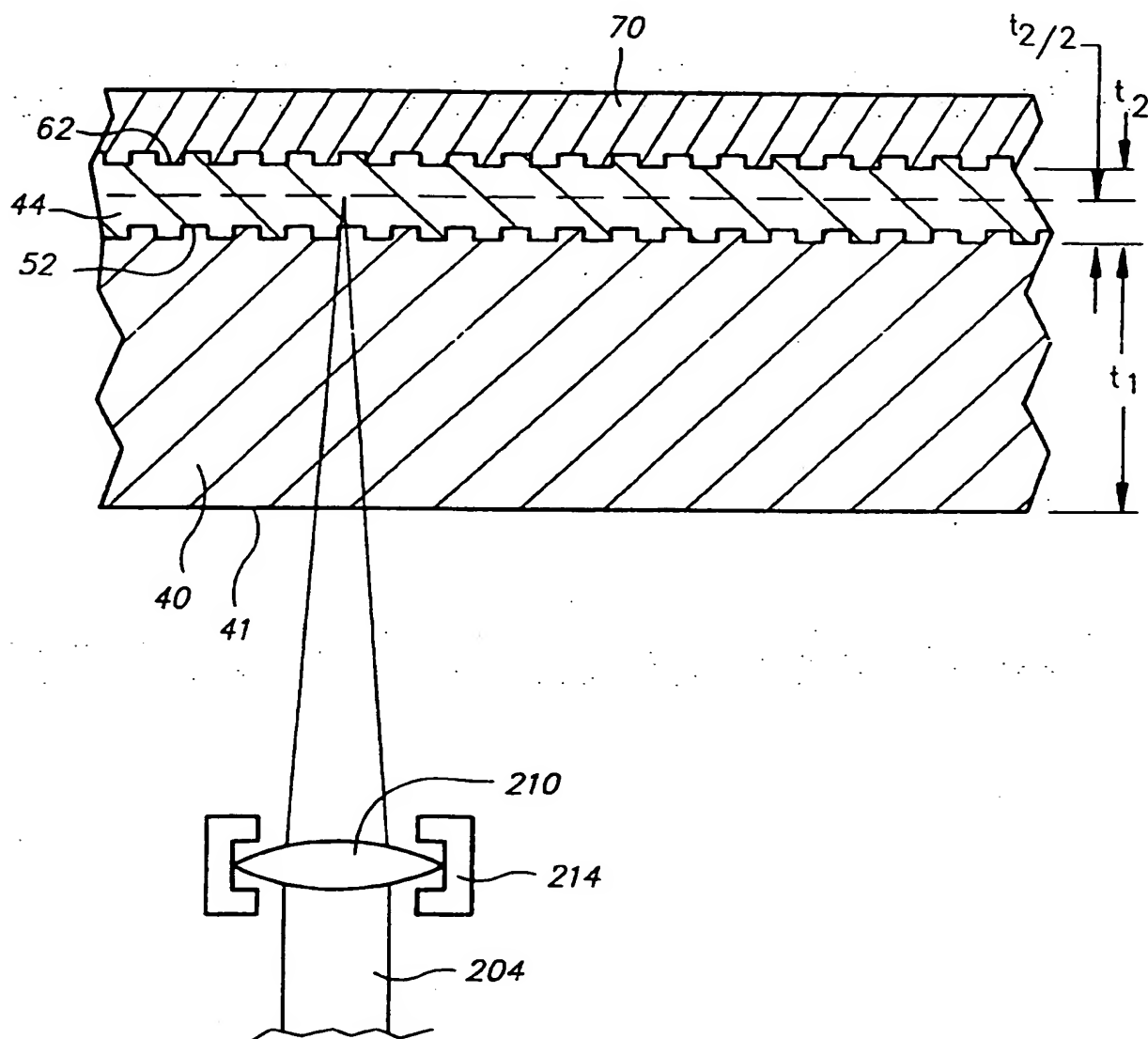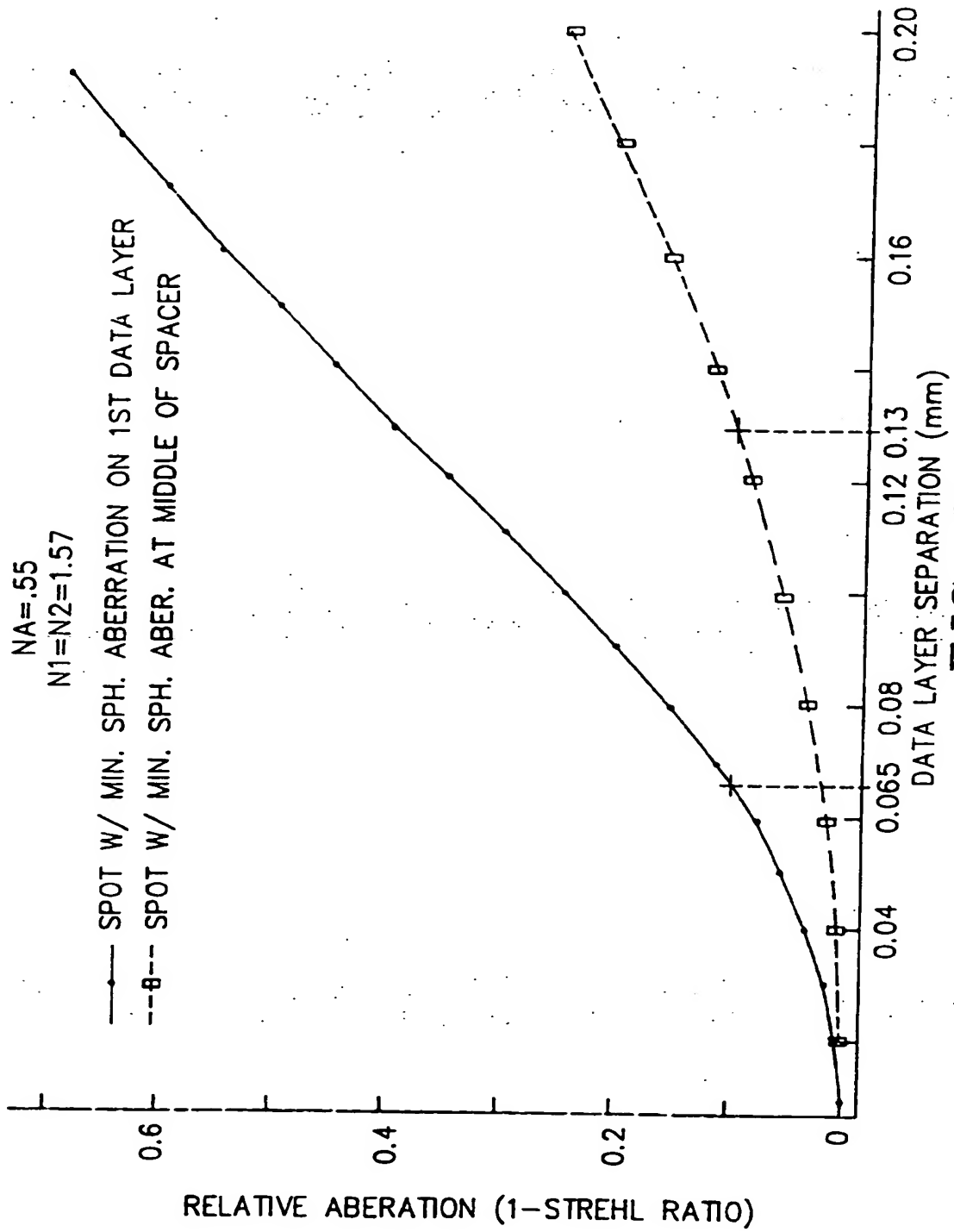
FIG. 3

FIG. 4

FIG. 5

N.A.=0.45
—— n=1.57
– – – n=1.10

SPOT LOCATION DEVIATION (mm)

STREHL RATIO

FIG. 6

NA=.55
N1=N2=1.57

—— SPOT W/ MIN. SPH. ABERRATION ON 1ST DATA LAYER
--8-- SPOT W/ MIN. SPH. ABER. AT MIDDLE OF SPACER

FIG. 7

DATA LAYER SEPARATION (mm)

RELATIVE ABERATION (1-STREHL RATIO)
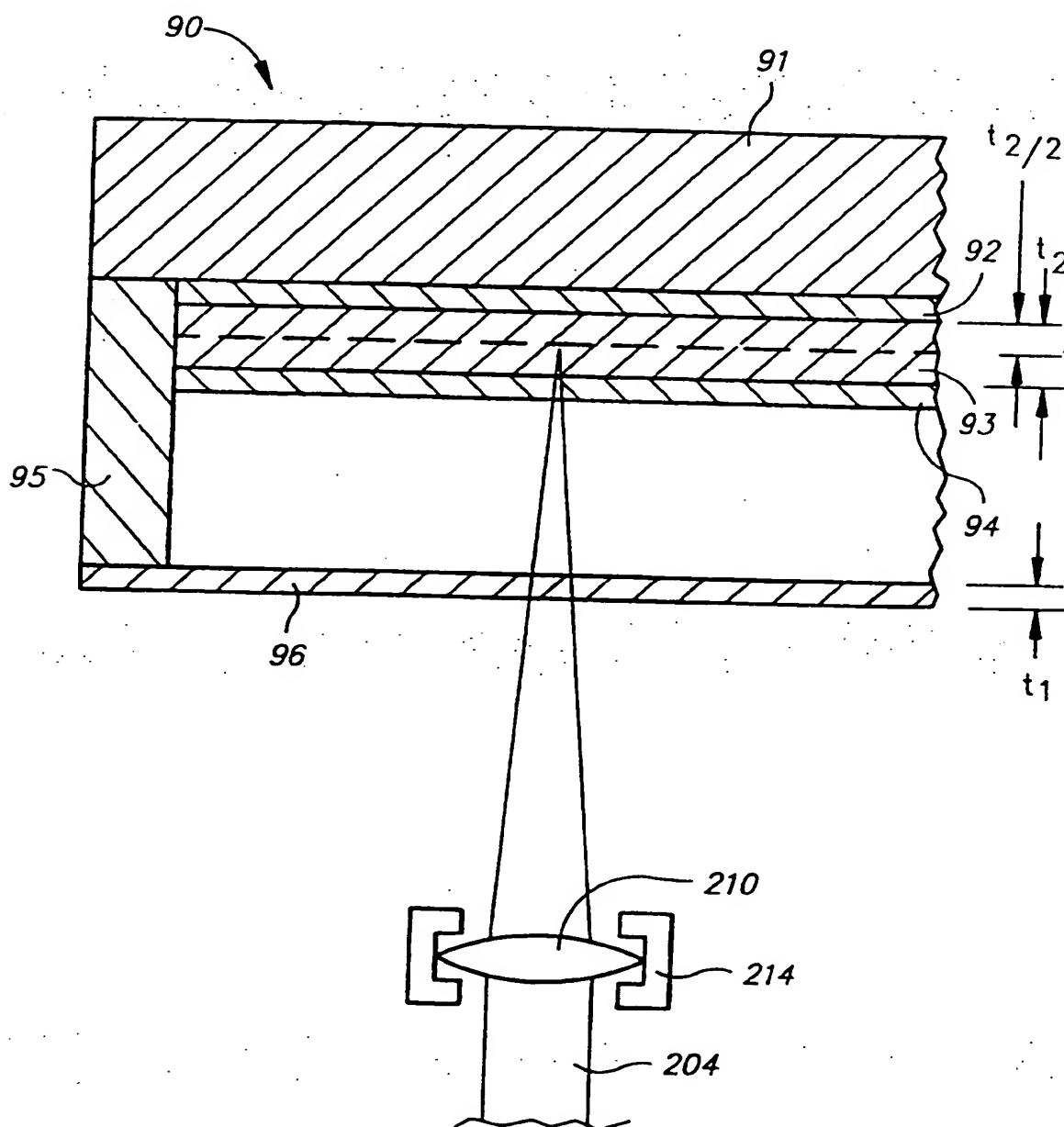
FIG. 8

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6   G11B7/135   G11B7/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6   G11B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	US,A,5 414 451 (SUGIYAMA HISATAKA ET AL) 9 May 1995 see column 10, line 65 - column 12, line 15 see column 28, line 60 - line 63 see column 32, line 65 - line 68	1-7,9, 11,12
X	& JP,A,05 101 398 (HITACHI) 23 April 1993 ---	1-7,9, 11,12
A	US,A,5 251 198 (STRICKLER JAMES H) 5 October 1993 ---	
E	WO,A,96 06427 (PHILIPS ELECTRONICS NV ;PHILIPS NORDEN AB (SE)) 29 February 1996 see page 13, line 1 - page 14, line 27 -----	1-6,11

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 May 1996	2 0. 06. 96

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl. Fax (+ 31-70) 340-3016	Holubov, C

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-5414451	09-05-95	JP-A- 5101398	23-04-93
US-A-5251198	05-10-93	NONE	
WO-A-9606427	29-02-96	NONE	